20 CROPPING SYSTEMS, SOIL FERTILITY, AND FERTILIZER USE

Cropping systems, including monocropping, sequential cropping, intercropping, mixed cropping, ley farming, and other systems, can be traced back to time immemorial. A reference to crop rotations (sequential cropping) can be found in Indian agriculture dating back to the Chalcolithic period, that is, before 1000 B.C. (Raychaudhri and Mira, 1993); in Chinese agriculture during the Han dynasty in the second century (Hsu, 1980); and, of course, in ancient Greece and Rome (White, 1970). The key to a successful crop rotation was a soil restorer crop of legumes such as beans (*Vicia faba* L.), various clovers, medicago species, lupins (*Lupinus album* L.), and vetch (*Vicia sativa* L.). These restorer crops provided sustainability to 3- to 5-year crop rotations. The famous English Norfolk rotation popular in the eighteenth century (Martin et al., 1976) consisted of turnip, barley, clover, and wheat in a 4-year sequence. Crop rotations were also practiced in colonial United States. For example, at Monticello, Thomas Jefferson followed a 5-year rotation of wheat-corn/potato-pea (*Pisum sativum* L.)-rye (*Secale cereale* L.)/wheat-clover/buckwheat (*Fagopyrum esculentum* Moench) (Karlen et al., 1994). The prevailing thought was that each of the crops in the rotation obtained their nutrients from different soil layers. Even today only 20% of the corn in the United States is grown in continuous monoculture, but most of the remaining 80% is grown in a 2-year rotation with soybean or in short (2- or 3-year rotations) with alfalfa, cotton, dry bean, or other crops (Power and Follet, 1987).

20.1. LEGUMES IN CROP ROTATIONS

As already pointed out, the soil restoring nature of legumes in crop rotation was known by ancient farmers. It was only in 1888 that Hellriegel and Wilfarth discovered *Rhizobia* in the root nodules and the N-fixation capacity of legumes. Since then there have been numerous reports from all regions of the world on the N contribution of legumes to succeeding crops. Most of these reports use

the fertilizer replacement value as the method for assessing N contribution from legumes in rotation with nonlegume crops such as corn or grain sorghum. After reviewing several such studies Bullock (1992) concluded that the replacement method overestimated the N contribution from legumes grown in rotation with nonlegumes and underestimated the overall rotation effect. For example, fertilizer recommendations for corn following alfalfa in the United States credit alfalfa with N contribution of 100 to 125 kg N ha^{-1} (Fox and Pickielek, 1988) based on the fertilizer replacement methodology. The actual contribution measured with ^{15}N methodology was only 24 kg N ha^{-1} (Harris and Hesterman, 1990). Several such reports are available in the literature and suggest that benefits of growing legumes or other crops in a crop rotation include factors other than just N effects. Some of the effects could be as follows:

1. Increase in the P, K, and micronutrient concentration and uptake of the crops succeeding legumes. For example, Copeland and Crookston (1992) reported that potassium and total micronutrient content increased in corn grown in a 2-year rotation with soybean, as compared with continuous corn. One of the reasons for such effects could be the fact that legumes can feed the deeper layers of soil and part of the nutrients absorbed are left in the root mass.
2. Increase in the water use efficiency.
3. Lessening of disease and pest problems. Francis and Clegg (1990) stated that the greater the difference between crops in rotation in sequence, the better the cultural control of pests. Pests that are controlled by crop rotations have the following characteristics: (a) The pest inoculum source must be from the field itself; this includes soil and root dwelling nematodes and soilborne pathogens; (b) a narrow range of the hosts; and (c) incapability of surviving long periods without a living host.
4. Better control of weeds. For example, in Nebraska rotating corn and grain sorghum with broadleaf crops is an effective methods of controlling shattercane (*Sorghum bicolor*). Van Heemst (1985) ranked 25 crops for their ability to compete with weeds based on the mean reduction in yield resulting from controlled weed infestations. Wheat was considered most competitive and given the first rank; sorghum ranked fourth and corn seventh.

20.2. INTERCROPPING SYSTEMS

In several tropical countries the per capita availability of land is decreasing daily, creating an urgent need to produce more and more food from the same piece of land. Intercropping systems permit the growing of a bonus crop along with the main crop. Intercropping is generally recommended for crops that are widely spaced such as corn, sorghum, pigeonpea (*Cajanus cajan* L.), and

pearlmillet (*Pennisetum typhoides* L.). The intercrop may be a grain legume such as mungbean (*Vigna radiata* L.), urdbean (*Vigna mungo* L.), cowpea (*Vigna unguiculata* L.), or an oilseed such as groundnut (*Arachis hypogaea* L.). The intercrops are not necessarily sown and harvested at exactly the same time, but they grow together for a large part of their growth period. The intercropping systems may be an additive series where the intercrop is grown in addition to the main crop or a replacement series where the two crops may be grown in different row ratios such as 1:1, 2:1, etc.; one crop replaces the other crop as far as the area is concerned.

Intercropping systems generally result in increased productivity from the same piece of land. Observed major advantages of intercropping systems are (1) better utilization of solar radiation; (2) better water use efficiency; (3) yield advantages under stress water conditions; and (4) better control of weeds, pests, and diseases (Chatterjee and Mandal, 1992). Because of fewer alternatives, intercropping is used less in temperate than in tropical regions.

Regarding nutrient management, legumes grown as an intercrop do not compete for nitrogen with the component crop. On the contrary, legumes may provide some nitrogen benefit to the associated crop. For example, Bandyopadhyay and De (1986) used N^{15} data to show that sorghum derives part of its nitrogen from a soil pool enriched by concurrently grown legumes. Other nutritional benefits have also been attributed to the legumes grown as an intercrop. For example, Yadava (1986) reported that the efficiency of P applied in sugarcane (*Saccharum officinarum* L.) increased from 3.5% in sole cropping to 15.8% when sugarcane was intercropped with mungbean. Experiments conducted under the All India Coordinated Project on Cropping Systems Research on fertilizer application in intercropping systems reveal that application of the recommended dose of fertilizer was adequate for cereals, but only 25% of the recommended dose was required for the legume (Chatterjee and Mandal, 1992). Thus from the soil fertility viewpoint, as well as overall productivity viewpoint, the intercropping systems hold considerable promise, especially for tropical regions of the world.

When arable crops are grown as intercrops in alleys between tree rows, the term generally used is alley cropping. For example, cowpea, sorghum, castor (*Ricinus communis* L.), and other crops can be grown in alleys of Leucaena (*Leucaena latisiliqua* [L.] Gillis; syn *L. leucocephala* [Lamb.] de Wit) (Singh et al., 1989). This system is very efficient in utilizing water resources and conserving the soil. In harsh climates the trees protect the alley crop, and cuttings from the branches can be used as a mulch.

Another term that needs to be mentioned is mixed cropping. Mixed cropping is a practice in arid regions of the world where the seeds of a number of crops such as pearlmillet, mungbean, and mothbean (*Vigna aconifolia* [Jacq.] Marechal) are mixed and sown together at the onset of rains. This practice assures the growth of at least one of these crops, regardless of the weather that follows. The farmers can depend on getting some harvest as determined by the amount and distribution of rainfall received. In regions where crop

Table 20.1 Changes in Input Response Pattern in System Requiring NPK + FYM for Maximum Yield (Example of Maize at Palampur)

Item	1973–1975	1982–1984
Total grain response to NPK + FYM (kg ha^{-1})	4825	5866
Percent contribution of N alone	51	0
Percent contribution of P (over N)	22	42
Percent contribution of K (over N + P)	0	23
Percent contribution of FYM (over NPK)	27	35

From Tandon. 1989. Fert. News 34(4):21–26. With permission.

production potential is greater, crops grown alone generally produce better than when grown in a mixture.

20.3. CROPPING SYSTEMS AND SOIL FERTILITY

Continuous cropping and removal of a harvest year after year without adequate and balanced fertilization can lead to soil fertility problems. Plant nutrients are depleted and this can show up in crop yields and response to applied fertilizer. Results from multilocation, long-term fertilizer experiments in India (Tandon, 1989) have brought out several interesting points in this respect. For example, from 1973 to 1975 at Palampur, 51% of the increase from NPK and FYM resulted from N alone. By 1983 to 1984 crop yield response to N alone dropped to 0; NPK and FYM were applied due to depletion of soil P and K (Table 20.1). The contribution of P during the same period increased from 22 to 42%, and K responses increased from 0 to 23%. Similarly, at Pantnagar (Table 20.2) in earlier years, only N produced a substantial increase in the yield of rice and wheat, but with the passage of time, P, K, and Zn also became more responsive. Such results send out important messages for continuously monitoring and revising fertilizer schedules for cropping systems as a whole.

The matter of concern is that in many cases this depletion of P and K is rather poorly reflected in soil test values over time. Further research is therefore necessary to develop more sensitive soil test methods.

20.4. FERTILIZER APPLICATION IN CROPPING SYSTEMS

While adequate fertilization of all the crops grown in a cropping sequence is the best policy, many developing countries do not have adequate indigenous fertilizer production and imported fertilizers are expensive. For this reason optimum utilization of applied fertilizer and economy in their use in a crop sequence has been the goal of several research investigations. This is especially important for nutrients like P and Zn, which are not easily lost from the soil. For example, studies in India have shown that in crop sequences such as rice-rice, rice-wheat, and maize-wheat (the first crop grown during rainy season,

Table 20.2 Changes in Input Response Pattern of Rice and Wheat in System Requiring NPK + Zn (Pautnagar)

Item	Rice		Wheat	
	1972–1974	1982–1984	1972–1974	1982–1984
Total response to NPK + Zn (kg ha^{-1})	1376	2867	2469	2132
Percent contribution of N	66	43	102	75
Percent contribution of P	–6	0	–5	7
Percent contribution of K	21	29	0	7
Percent contribution of Zn	18	28	2	11

From Tandon. 1989. Fert. News 34(4):21–26.

Table 20.3 Some Strategies for Allocation of Fertilizer P in Cropping Systems in India

Cropping systems (2 or 3 crops a year)[a]	Annual input (kg P_2O_5/ha)	Allocation strategy
Wheat-mungbean-pearl millet	60	60 to wheat
	90	60 to wheat, 30 to mungbean, 30 to millet
	135	90 to wheat, 15 to mungbean, 30 to millet
Wheat-pearl millet	75	45 to wheat, 30 to millet
	120	60 to wheat, 60 to millet
Potato-wheat-rice	90	60 to potato, 30 to wheat
Cotton-wheat	90	60 to wheat, 30 to cotton
Soybean-wheat	50/100	All to soybean or 1/2 to soybean and 1/2 to wheat

[a] Wheat: November–April; mungbean: May–June; pearl millet/rice/cotton/soybean: June–July–October/November; potato: September–November/ December.

From Tandon. 1993. *Fertilizer Management in Food Crops*, p. 191. With permission of the Fertilizer Development and Consultation Organisation, New Delhi, India.

that is, July to October and the second crop during the autumn-winter season, that is, November to April), adequate P fertilization of the winter crop could be sufficient for the entire one-year crop rotation; the rainy-season crop could be grown on residual P (Kundu and De Datta, 1988; Kolar and Grewal, 1989). Some strategies for allocation of fertilizer P in different cropping systems are given in Table 20.3. Similarly, for the rice-wheat cropping system on Zn-deficient alkaline soils of Ludhiana (Punjab, India) 5 kg Zn/ha was optimum for rice, while an application of 10 kg Zn/ha to rice was required if the Zn needs of the following wheat were also to be met (Thakkar et al., 1989).

In temperate regions often responses to fertilizers are greater in rotation than in monoculture. For example, Varvel and Peterson (1990) showed that N responses by corn, as well as absolute yields, were greater when grown in rotation than when grown as a monoculture. Part of this response may be due to less weed and disease pressure in the rotation. Also, probably the soil organic N in rotations is more labile than that in monocultures.

An FAO-sponsored workshop "Expert Consultation on Fertilizer Use Under Multiple Cropping Systems" held at New Delhi in 1982 made the following fertilizer scheduling recommendations (FAO, 1983):

1. Rice-based cropping systems
   a. Irrigated rice
      (1) Rice-wheat sequential system: for alluvial soils in the Indian subcontinent, N to be applied to both crops, P to be applied to wheat, and K and Zn to be applied to rice.

   (2) Rice-rice-mungbean or soybean sequential system: N to be applied to both the rice crops, while P to be applied only to one (preferably the second, dry season) rice crop together with K, S, and Zn on the basis of soil tests.
   (3) Rice-jute sequential system: N to be applied to both crops; P, K, S, and Zn, if needed, to be applied to jute.
  b. Rainfed rice
   (1) Rice-chickpea, rice-lentil, rice-horsegram, rice-niger, rice-mustard, rice-linseed, rice-groundnut, and rice-soybean sequential systems: N, P, and other nutrients, as required, to be applied to rice crop, only 20 kg P_2O_5/ha to be applied to the sequential legume crop if moisture conditions are favorable.
   (2) Rice + pigeonpea, rice + maize, rice + cassava, rice + *Leucaena leucocephala*, and rice + kenaf intercropping systems: N, P, and K to be applied to the rice crop only; Zn and Fe to be applied to rice when needed (iron as foliar spray).
2. Maize-based cropping systems
  a. Humid tropics
   (1) Maize-cowpea sequential system:
   (2) Maize + cassava, maize + groundnut, and maize + *Phaseolus* bean intercropping systems:
   (3) Maize + grain/cowpea alley cropping with *Leucaena leucocephala*.
  b. Subhumid tropics
   (1) Maize + pigeonpea, maize + soybean, maize + cowpea, and maize + chickpea/safflower (for deep Vertisol areas with 200 mm plant-extractable water per meter depth) intercropping systems: N to be applied to maize only; P to be applied to maize and associated legumes; K, S, and Zn to be applied to maize when needed.
3. Sorghum-based cropping systems for semiarid tropics
  a. Sorghum + pigeonpea, sorghum + mungbean, sorghum + cowpea, and sorghum + groundnut intercropping systems.
  b. Sorghum-yam and sorghum-chickpea/safflower sequential systems: N, P, K, S, and Zn to be applied to sorghum only.
4. Cassava-based cropping systems for humid tropics
  a. Cassava + maize/beans intercropping systems: fertilizers to be applied to either crop, according to its importance in the region.
5. Inclusion of leguminous green manure or forage legume prior to an irrigated rice crop can contribute 30 to 40 kg N/ha.
6. Inclusion of grain legumes such as mungbean or cowpea in the cropping systems can contribute 20 to 25 kg N/ha.
7. Inclusion of blue-green algae/Azolla in the irrigated rice crop can contribute 20 to 25 kg N/ha.

8. Leucaena sown at 4-m spacing can contribute, from top prunings incorporated in the soil, up to 60 kg N/ha to the companion crop.
9. Fertilizer applications should be based on local experience and on the corresponding soil tests. In formulating N rates, due consideration should be given to the contributions from associated leguminous crops grown in the system.

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